Notes from the MQX Cryostat Interim Design Review

Introduction

An interim design review of the LHC inner triplet quadrupole cryostat (MQXL) was held at LBNL on 13 March 2000. This review was designed to bridge the gap between the Conceptual Design Review conducted in December 1998 and a full Engineering Design Review planned for later this year after the first prototype cryostat has been built.

This interim review was timed to take place shortly before procurements start for the first prototype cryostat, which will house the first full-length prototype MQXB quadrupole. The design of the prototype cryostat was the focus of the review, with appropriate reference being made to the designs of the final cryostats for the Q1, Q2a-Q2b and Q3 assemblies. Topics covered included closure of the magnet helium containment vessel, magnet supports, heat shields and piping, the 1.9K heat exchanger, external cryostat supports, the warm-cold transition, and interfaces and interconnects.

The primary goal of this review was to cause discussion to take place resulting in comments and recommendations that will be helpful in reaching the final design, for the prototype cryostat and ultimately for the production cryostats. A secondary goal was to evaluate which component designs are sufficiently mature to allow early procurement for the production series.

The review committee consisted of:

- Phil Pfund, FNAL
- Jim Strait, FNAL
- Mike Lamm, FNAL
- Tom Peterson, FNAL
- Steve Plate, BNL
- Tom Taylor, CERN
- Ranko Ostojic, CERN
- Rob van Weelderen, CERN
- Antonio Perin, CERN
- Jon Zbasnik, LBNL

Notes and Comments

1. *Vacuum vessel material*: The vacuum vessel material has not yet been selected. The difficulty is in meeting the CERN criterion for impact strength at –50^{o}C. The SSC and RHIC vacuum vessels did not have such a requirement and relatively inexpensive grades of carbon steel were used in their construction. The vacuum vessel for the first prototype (Q2P1) is planned to be constructed of a similar grade of steel (SA 516) since it will only be tested at FNAL and not delivered to CERN. The current estimated cost of meeting the CERN requirement is about $16K per vessel or about $600K, including overhead, for all inner triplet quadrupoles. There would be a comparable cost impact for the beam separation dipole vacuum vessels. FNAL is continuing to search for suitable and economic material.

2. *Tie rods*: Tie rods will be used to restrain vacuum loads across bellows. A concern was raised whether the tabs to which the tie rods are attached will protrude too far into the aisle. This needs to be checked. However, during the review of the DFBX it was suggested that three tie rods be used instead of two which would provide greater stability and move the rods away from the horizontal location where they would have protruded the most into the aisle. (Since the review, it was determined that four tie rods, would be easier to position than three.) A question was raised whether tie rods allow enough lateral motion to make small adjustments in x-z alignment after cool-down. The load of the tie rods on the O-ring flange may be localized to a few of the bolts near the tabs that support the rods, and may strain the O-ring flange enough to affect the seal. The cryostat designers should analyze the stresses and deflections of the vacuum rods, bolts, and ring structure.

3. *Overall size of Q2*: The Q2 vacuum vessel, while shorter than the arc dipole vacuum vessel, is nominally the same diameter. It has additional height and width because of the square stiffening braces at the location of the cold mass supports. It was recommended that the width be checked for transport and in-situ clearances. Since the review meeting adjourned it was confirmed that the width of the stiffening sections is 1000 mm. However, the largest width is the OD of the vacuum flange which is the same diameter as that of the arc dipoles (1055 mm). The height at 1100 mm and the diagonal measure at 1487 mm are not likely to pose a problem but should be checked nevertheless.

4. *Cold mass support*: The support rings are attached to the vacuum vessel and do not move during cool-down. The attachment points to the cold mass do move axially with cool-down and the lug support system is designed to accommodate this shrinkage through a sliding mechanism. Welding of the base pads to the cold mass is critical to alignment of the slide system. Assembly tooling will be required to reference the cold mass to the support spider and to drilling support bolt holes in the welded bracket. A decision must be made in the near future whether the support lugs for the KEK quadrupoles will be welded in Japan or by Fermilab.

5. *Sliding system for cold mass support*: The design of the lug system is well along and is currently under test to determine sliding friction at operating temperature. The slide material, which has been used in the Tevatron and SSC, is believed to have a small amount of Teflon in it. It is unknown whether this material is acceptable in the LHC due the general prohibition to Teflon. No tests of any irradiated samples of this material have been done, nor are any planned. Fermilab needs to work with CERN to reach a decision on the acceptability of the current slide material. If the current material is determined to be unacceptable, a possible alternate material is a low-friction coating of stainless steel that CERN is testing for the beam screen. If this material is unsuitable as a slide material, radiation tests on the current Teflon containing material should be considered.

6. *Heat transfer between cryogenic lines*: The supply and return lines to the thermal shield may be thermally shorted to each other by the shield. The same is true for the 4.5 – 20 K supply and return lines. The thermal correspondence between each of

these pairs of supply and return lines should be checked to confirm that they will not result in a heat transfer path which would leave one end of their respective cooling circuits unacceptably warmer than the other.

7. *1.9 K vapor exhaust*: On one side of each IP, the Q1 is at the low end of the incline. The concern was raised that a liquid trap might form which would obstruct the flow of 1.9 K vapor from the heat exchanger. A similar concern was previously raised for the D1. The liquid supply tube, when extending through the triplet end of Q1, should have a cap or elbow on the end so that spray is directed laterally. A recommendation was made to consider a liquid indicator and heater to remove collected liquid. A liquid indicator should be at least redundant or exchangeable in situ. Fermilab is developing a design for a passive heating system which might be used as an alternative.

8. *Beam position monitor*: CERN will design and supply a BPM at the IR end of Q1. The amount of space that needs to be reserved for this BPM is unknown and needs to be specified by CERN. The interface specification for this region needs to be developed.

9. *Heat exchanger test*: The full-length model of the triplet heat exchanger is expected to be commissioned at CERN by May, with testing starting by mid June and finished by the end of August. This schedule will enable the design to be confirmed just in time for the cryostat EDR and to support the design and procurement of components for the production cryostats.

10. *KEK end plate*: The current design strategy is to attach correctors to the end plates of the cold masses. Correctors will be attached to the non-IP end of Q1, between Q2a and Q2b, and both ends of Q3. Design details for the KEK end plates are unknown. This information is required to confirm the attachment design with CERN.

11. *Interconnections*: CERN prefers that pipe welds in the interconnect regions be done with automatic welders. Automatic welds are preferred because CERN-TIS is more tolerant of automatic welds than manual welds. It is not clear that there is sufficient space for orbital welders in all locations. This needs to be checked. RHIC experience is that some interconnects were difficult to align well enough for automatic welding. It is not clear if the flange design is compatible with the CERN orbital welders. CERN will provide the beam tube hardware through the interconnect, between two Fermilab-provided flanges. CERN also needs to specify the beam tube arrangement for the interconnect region, specifically the amount of space that is required.

12. *Beam Tubes*: The cold bore tube is considered to be part of the cryostat assembly task. The cold bore tube design is not yet well developed and was not considered during this review. However, this is an important component and its design must be carefully reviewed, together with the liners (see below) before design is finalized for series production.

13. *TAS2 and TAS3*: Little thought has been given to the designs or method of support of the intermediate absorbers TAS2 and TAS3, which are located in the interconnects between Q1 and Q2 and between Q2 and Q3 respectively. Their absorber cooling requirements also need to be specified.

14. *Q2a – Q2b connection*: The current tooling concept determines the transverse alignment of the Q2a relative to the Q2b by attachment to the cold mass shell. A tolerance analysis needs to be done to determine if this is likely to be adequate, and provision needs to be made to measure the relative alignment of the quadrupole axes of the two model magnets that will be welded together in an initial test this spring.

Summary of Action Items

The following action items are taken from the discussion above.

1. Vacuum vessel material
   1.1. FNAL: Continue to search for a suitable and economic material.
2. Tie Rods
   2.1. FNAL: Consider more than two tie rods.
   2.2. FNAL: Check to verify that the tie rods will not protrude too far into the aisle.
   2.3. FNAL: Confirm that the tie rods allow enough lateral motion to make small adjustments in alignment.
   2.4. FNAL: Verify that the stresses and deflections in the tie rod system do not affect the vacuum seal.
3. Overall size of Q2
   3.1. FNAL: Check the width (also the height and diagonal measure) of the vacuum vessel for transport and in-situ clearances.
4. Cold mass support
   4.1. FNAL and KEK: Determine which organization will weld the support to the KEK cold masses.
5. Sliding system for cold mass support
   5.1. FNAL and CERN: Determine the acceptability of the current candidate slide material.
6. Heat transfer between cryogenic lines
   6.1. FNAL: Check the thermal correspondence between supply and return lines.
7. 1.9 K vapor exhaust
   7.1. FNAL: Consider design alternatives to minimize the potential for liquid to collect and block the vapor flow.
8. Beam position monitor
   8.1. CERN: Specify the space to be reserved for the BPM.

8.2. FNAL and CERN: Develop the interface specification for the region containing the BPM.

9. Heat exchanger test

   9.1. CERN and FNAL: Complete the heat exchanger test in time to support the design and series production of cyrostats.

10. KEK end plate

    10.1. FNAL: Obtain detail of the design of the end plates from KEK to confirm the attachment design of correctors.

11. Interconnections

    11.1. FNAL and CERN: Check the clearances in the interconnect regions for orbital welders.

    11.2. CERN: Specify the space required around the beam tube in the interconnect regions.

12. Beam tubes

    12.1. FNAL: Arrange for review of the cold bore tube.

13. TAS2 and TAS3

    13.1. FNAL: Compete the design of the absorbers.

    13.2. FNAL: Specify the cooling requirements of the absorbers.

14. Q2a – Q2b connection

    14.1. FNAL: Analyze the alignment tolerance of the Q2a-Q2b connection to determine whether it will achieve the tolerances required for the cold masses.

    14.2. FNAL: Measure the relative alignment of the two model magnets in the connection test.